UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

# STUDY OF HEIGHT AND FREQUENCY OF WAVES ACTING ON TAILRACE SLOPES AND RIVERBANKS DURING 1949 FLOOD SEASON

## GRAND COULEE DAM

## COLUMBIA BASIN PROJECT

Hydraulic Laboratory Report No. 336

ENGINEERING LABORATORIES BRANCH

DESIGN AND CONSTRUCTION DIVISION
DENVER, COLORADO

November 28, 1952

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Design and Construction Division
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Laboratory Report No. 336
Hydraulic Laboratory
Compiled by J. C. Schuster
Checked by J. W. Ball

Subject: A study of the height and frequency of waves acting on the tailrace slopes and riverbanks during the 1949 flood season at Grand Coulee Dam--Columbia Basin Project

## PURPOSE

By field and model tests, obtain data for predicting the characteristics of the wave action in the river below Grand Coulee Dam at large floods--the information to be used in determining the adequacy of proposed riprap protection to the tailrace slopes, river banks, and river channel.

## CONCLUSIONS

1. The wave action generated by the spillway flow in the Columbia River immediately below Grand Coulee Dam, is irregular. The frequencies vary from 0.6 to 1.5 waves per second and the heights from 3 inches to 7.5 feet for flows in the neighborhood of 300,000 cfs.

2. Waves between 15 and 20 feet high can be expected along the river banks below Grand Coulee Dam during a capacity flood of 1,000,000 cfs.

3. Much of the riprap material placed on the tailrace slopes and river banks below the dam will be disturbed by wave action. Rocks up to 6 inches will be tossed together with logs and other debris into windrows along the shore. There will be considerable readjustment of larger material particularly where the slopes are steep or piles of the material exist. Much of this readjustment will take place as a result of the smaller material being washed from between and beneath the larger, causing the latter to roll down the slopes. This action was observed, as well as recorded by survey The records are shown as Figures 11, 12, 13, 14 and 15 of this report.

4. Approximate wave heights and frequencies such as those occurring at Grand Coulee Dam during flood periods can be recorded satisfactorily by means of staff gages and a motion picture camera.

5. The nature and appearance of the wave action on the 1 to 60 model is not similar to that on the prototype at flows corresponding to less than approximately 350,000 cfs. The spillway flow on the model does not plunge through the water in the bucket to form a roll over the bucket lip as on the prototype in this capacity range.

6. The nature and appearance of the wave action at higher flows on the model are similar to those for the prototype, but measurements indicate the model wave heights to be relatively smaller at representative discharges.

7. The relationship between wave height and discharge was linear for the model and data indicated it should be the same for the prototype, even though the air entrainment and viscosity are not to scale. The wave height of 15 to 20 feet given in (2) above is based on this linear relationship.

8. A general reduction in velocities in the river channel below the dam will result from the resloping of the tailrace slopes and river banks, and the reshaping of the river channel. The currents adjacent to the banks should be less severe, and this, together with the flatter slopes, should provide a more stable riprap surface.

## ACKNOWLEDGMENT

The work covered by this report was performed at the project during the months of May and June 1949, under the direction of James W. Ball and D. M. Lancaster of the Denver Hydraulic Laboratory, who wish to acknowledge the able assistance of project personnel in the successful accomplishment of this assignment.

## INTRODUCTION

### Background Information

In the early construction plans (1935) only the excavated slopes of the powerhouse tailraces below Grand Coulee Dam were to receive a protective armor of riprap. That this protection would not be adequate to prevent severe damage to the tailrace slopes and riverbanks during large floods was indicated by tests on a 1:120 scale model representing the construction stage in which the flood waters were diverted through the west cofferdam area. The testing was continued in 1936, and in view of the results and the abundance of rock available on the project during construction. the thickness and extent of the riprapped surfaces were increased over that tested in the model. Operation of the spillway and experience with slides in the riverbanks below the full-sized structure, in a few seasons previous to 1944, served to emphasize the importance of providing adequate protection in these areas. As many pertinent model tests as time would allow were made in 1944 on the 1 to 60 model at the project. From the test program it appeared that slopes of 6 to 1 would be required in areas attacked severely by waves and that the slopes could be steepened in areas where the size of the waves decreased.

The problem of resloping and protecting the riverbanks was again explored by tests on the 1 to 60 model during the period May to August of 1945 as a continuation of the work done in 1944 and reported in Hydraulic Laboratory Report 174. Using the results of the two studies as a guide and resloping the tailrace surfaces and riverbanks of the model to form a gradual transition from the tailraces to the natural riverbanks a short distance upstream of the highway bridge, a satisfactory treatment was evolved, giving a minimum of movement along the banks. At this time, a comparison of wave heights from the model and prototype disclosed that the waves were more severe at small discharges in the prototype than was indicated by the model; and it was believed that a better correlation of data would result at higher corresponding discharges.

In the intervening period from August of 1945 until the latter part of 1948, some resloping of the riverbanks was carried out, but no information of particular value concerning the size of the riprap stone required for waves of different heights was obtained. Considerable damage to the slopes occurred during the flood of 1948 when riprap was removed from some of the vulnerable areas adjacent to both tailraces. The greatest damage occurred on the left side of the river where the slopes were steepest and where areas of the underlying clay surfaces became exposed. In January of 1949, a board of consultants made a field examination and review of possible river channel improvements immediately downstream from Grand Coulee Dam. In this connection, motion pictures of the behavior of the waves generated in the tailrace and channel areas during the 1948 flood were shown; they were especially valuable in weighing the evidence of damage to the channel slopes and in judging the extent and character of additional bank protection which should be supplied. During this conference, the hope was expressed that arrangements would be made during future flood flows to secure motion pictures of the spillway bucket and the waves in the adjacent downstream portions of the river channel in even greater detail than was accomplished in 1948.

A memorandum from J. J. Hammond to the Chief Designing Engineer, dated April 13, 1949, subject "Wave height for determination of riprap rock sizes--Channel Improvement--Grand Coulee Dam" recommended that data be obtained on the wave action in the tailrace and along the river channel during the flood season of 1949. In conjunction with these measurements, tests at corresponding discharges were to be made on the 1:60 scale model for correlation. This plan was subsequently approved, and Messrs. Ball and Lancaster of the Hydraulic Laboratory carried out the program of obtaining information concerning wave heights in the Grand Coulee Dam tail bay during the period May 4 to June 17 of 1949.

## Test Facilities for Prototype

The height of waves acting on the riverbanks downstream of Grand Coulee Dam were obtained by photographing painted staff gages with a 16-mm motion picture camera during the flood season. The locations of the camera and gages are marked on a plan view of the Grand Coulee Dam tailbay (Figure 1). Staff gages No. 1, 2, and 3, for both right and left riverbanks (Figures 2A and B), were marked with a white band at 6-inch intervals on 6-inch standard pipe. Sections of 10-inch-diameter pipe 4 feet long were embedded in the riverbanks, within which, lengths of 6-inch pipe were placed and concreted. The 6-inch staffs were installed so that the highest on the left bank was identified by a single circular mark, the intermediate by two circular marks, and the lowest by three circular marks. The right bank had a similar identification system, except that triangular marks were used for identification. Staff Gages No. 4R and 4L were painted on the faces of the powerhouses in the bays of Units 5R and 5L, and extended from elevation 960 to 990 (Figure 3A). The gages were marked with white lines 6 inches wide at 6-inch intervals. A staff gage was painted on the 7-1/2-foot diameter No. 1 access shaft of the bucket caisson in the drydock (Figure 3B). This staff started at elevation 960 and extended to 995 and also was marked with white lines 6 inches wide at 6-inch intervals.

To obtain wave heights at positions 1, 2, 3, and 4 (Figure 1), the pile hammer suspended from the high line was painted on three sides (Figures 4A and B). The markings on this staff were 12-inch white bands at 1-foot intervals.

As a further aid in recording wave height, pressure cells were mounted at the bases of Staff Gages 2R and 2L. These cells were not used because the anticipated flood peak for this season did not materialize, thus leaving the maximum water surface in the tail bay below that at which the cells were placed. One additional pressure cell was mounted at the bottom of the pile hammer which was lowered into the river to record pressure variation below the water surface caused by the passing of waves at the surface. For recording surface variations with the camera, a rope staff was stretched between the cell and a point on the highline cable car. Flags were tied to this rope, red at intervals of 5 feet and white at intervals of 1 foot. The lowest red flag on the rope was 15 feet from the pressure cell, and the top red flag was 35 feet from the pressure cell. Two white flags (1-foot spacing) were placed above the top red flag.

## Test Facilities for 1:60 Model

Wave measurement. The 1:60 model of Grand Coulee Dam constructed and maintained near the site of the dam was placed in operation to obtain model wave data corresponding to that for prototype discharges. Because of the size of the model, instrumentation for obtaining wave action and height was different than that used in the prototype.

An electrical wave measuring system was used in the model. A schematic diagram of the electrical circuit used in this device appears in Figure 5G. Two electrodes consisting of pairs of stainless-steel rod were used in this equipment, one pair for balancing the electrical bridges in still water and the second for the actual wave measurement. To reference the device with the average water surface, Electrode B was completely immersed in still water, Electrode A was immersed to the midpoint of the pair of steel rods and the bridge circuit balanced to give a zero deflection on the galvanometer. The fluctuating water surface due to wave action varied the immersion of Electrode A and unbalanced the circuit in the direction of water movement. The amount of deflection of the galvanometer was directly proportional to the amplitude of surface displacement. The equipment permitted either a visual observation of the wave action on a screen in the form of a light trace from the galvanometer or a recording of the wave action on photographic paper in an oscillograph.

Velocity measurement. Water flow direction and velocity was obtained on the model for two tail bay topography plans, (1) present and (2) ultimate, using paper confetti, a stop watch, and a scale.

Test Procedure and Tabulation of Data

Prototype. Wave action and height on the various staff gages in the tail bay of the prototype structure were recorded for river flows of 266,000, 313,000, and 346,000 cfs. This was accomplished by taking 16-mm motion pictures at 16 frames per second of the staff gages from previously established camera stations. Data obtained were made directly usable by viewing each frame of the film in a microfilm reader, and tabulating per frame the water surface variation on each staff gage. These tabulated records were the means of obtaining the length of time of staff gage observations, the magnitude of the water surface fluctuation, and the average water surface by averaging the tabulated values.

In the use of the pressure cell mounted on the pile hammer, the pressure variation transmitted by the cell was recorded on photographic paper in the oscillograph. Moving pictures in color were utilized in photographing the water surface, and its action upon the rope staff placed above the pile hammer. Camera and oscillograph were started simultaneously for correlating surface fluctuation with pressure cell variation. Pressure and surface variations were recorded for two cell depths 14.45 and 29.60 feet below the surface. The color moving pictures were viewed and tabulated records made of the surface variation.

1:60 model. Wave action in the model was recorded for corresponding stations of the prototype as shown in Figure 1. The data for the model were obtained for discharges representing 400,000, 450,000, 500,000, and 750,000 cfs in addition to those taken on the prototype. These data were recorded graphically by the oscillograph, acting through the electrical wave measuring device. The water surface fluctuations of the model were obtained from the records by the use of suitable constants taken from the electrical circuit.

To measure the direction and velocity of water flow, paper confetti was dropped on the water surface. The direction of the flow was noted, and the velocity of the paper confetti was determined by using a stop watch to time the paper during its travel between two arbitrarily selected points.

## RESULTS OF WAVE STUDIES

Water Surface Fluctuation Prototype

For comparison of the maximum water surface fluctuation in both the model and prototype, the tabulated values taken from the motion picture film and the oscillograph records were utilized. The tabulated water surface elevations were used in the following way:

LOWEST STAFF RIGHT SIDE-1R

| | | | | |
|---|---|---|---|---|
| Discharge 266,000 cfs | 966.50 | | 5.00 | |
| | 7.50 | | 4.50 | |
| Water surface elevation | 967.50 | | 4.50 | |
| | 7.00 | | 4.50 | |
| | 7.00 | | 4.50 | |
| | 6.50 | | 4.50 | 2.0 foot |
| | 6.50 | | 4.50 | fluctuation |
| | 6.00 | | 4.00 | |
| | 6.00 | | 4.00 | |
| | 6.00 | 3.0 foot | 4.00 | |
| | 5.50 | fluctuation | 4.00 | |
| | 5.50 | | 4.00 | |
| | 5.50 | | 3.00 | |
| | 5.00 | | 3.00 | |
| | 4.50 | | 3.00 | |
| | 4.50 | | 3.00 | |
| | 4.50 | | 3.50 | |
| | 5.00 | 0.5 foot | 3.50 | |
| | 5.00 | | 4.00 | 2.0 foot |
| | | | 4.50 | fluctuation |
| | | | 4.50 | |
| | | | 5.00 | |
| | | | 4.50 | |
| | | | 4.50 | |

Water surface fluctuations were recorded as the number of feet elevation change between troughs and peaks, as indicated in Figure 5F. To establish a percentage for the occurrence of the various sizes of the waves the total number of each size in increments of 0.25 foot was compared to the total number of fluctuations indicated by the tabulation. These percentages were plotted against the amplitude of fluctuation in feet for each staff gage and discharges of 266,000, 313,000, and 346,000 cfs. Points plotted in the above charts were connected by straight lines, because no general curve seemed to average all of the points. (Figure 5). These data may be used for estimating the number of waves of each size to be expected at each of the five gaging positions in the tail bay for these river flows.

## Model and Prototype Conformity

Viscous resistance while negligible for waves longer than a few feet, becomes increasingly important for shorter waves, according to studies cited by J. W. Johnson in "Scale Effects in Hydraulic Models Involving Wave Motion" [1]. Height reduction due to internal friction becomes

1/Transactions, American Geophysical Union Volume 30 Number 4, August 1949.

significant for wave periods considerably less than 1 second as it also does for wave lengths shorter than 1 foot. Wave periods in the model were less than 1 second, varying to as low as approximately 0.2 second. The periods of the major prototype waves were greater than 1 second. Model wave lengths could not be obtained from the oscillograms and no definite observations were made of the prototype lengths although they were estimated from 20 to 100 feet.

Wave types in the model and prototype were similar. That is in deeper water prototype and model, the wave height (2 times the amplitude) was less than the depth; and in shallow water (that on the riprapped slopes) the wave height was greater than the depth. An oscillatory wave occurs in the first instance and a breaking wave in the second. Model waves broke upon the shore but they evidenced practically none of the prototype violence. Dynamic pressures of the prototype wave acting upon the slopes or walls for the waves which break, may result in peak pressures 10 times the maximum dynamic pressure $\frac{\rho V^2}{2}$ of the approaching wave according to G. H. Kenlegan, "Wave Motion"[2]. Model and prototype waves were apparently somewhat dissimilar in this respect.

A comparison of the height similitude of the wave action in the Grand Coulee tail bay with that in the model was based on an average fluctuation value (Figure 6A). Average values were used in the similitude ratio to minimize the effect of a maximum value that occurred in tests on either the model or the prototype. The maximum ratio of the average prototype to model fluctuation was 8.6 to 1 at the right bank and the minimum 1.8 to 1 at the caisson access shaft in the 1949 range of prototype discharge. Comparisons based on the maximum fluctuation values at the five measuring stations have ratios that varied from a maximum of 5.4 to a minimum of 2.5 for the 1949 flood (Figure 6B to 6F). A ratio of 1.4 to 1 occurred at the caisson access shaft station for the 1948 flood of 570,000 cfs. Available data were insufficient for Stations 1L, 1R, 4L and 4R to determine a curve which would indicate the ratio of model to prototype fluctuation.

Extrapolation of the model data for Station 1R to a maximum design discharge of 1,000,000 cfs results in a maximum water surface fluctuation of 12 feet. If, as indicated by data of Station 5R, the prototype fluctuation increases linearly with discharge, a prototype fluctuation of approximately 20 feet would be possible in the vicinity of 1R. Extrapolation of the data at Stations 1L, 4L, 4R, and 5R on the same premise, results in a maximum water fluctuation of approximately 21 feet.

There is photographic evidence of a flow pattern change in the vicinity of the roller bucket for model discharges representing 266,000, 346,000, and 500,000 cfs and a prototype discharge of 570,000 cfs (Figure 7 and 8). A roller of water is visible immediately downstream of the bucket at a discharge on the model representing 500,000 cfs. This roller is also visible but of less magnitude at discharges representing 266,000 and 346,000 cfs. The prototype has a definite roller at a discharge of 570,000 cfs and at all discharges in excess of about 100,000 cfs.

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2/ Engineering Hydraulics, Edited by Rouse.

The quantity of air insulflated by the water in the model roller bucket is relatively smaller than that of the prototype and does not remain mixed for a comparable distance downstream. The air quantity does increase with discharge.

The changes in flow conditions may be indicated by the decreasing values of the average prototype to model fluctuation, but the limited range of prototype discharge prohibited a definite conclusion (Figure 6A). The decreasing model to prototype ratio would indicate that scale effect decreases as the discharge increases although again limited discharge prohibited a definite conclusion (Figure 6B). It was concluded from the data that fluctuations on the banks in the vicinity of the staff gages were likely to be in the order of 15 to 20 feet for the design discharge of 1,000,000 cfs.

## Frequency of Surface Fluctuation

To determine the frequency of water surface variation at the five measuring stations, the total time of camera operation at 16 frames per second was obtained for each tabulation. The total number of fluctuations, 0.25 foot or greater, also obtained from the tabulations, was then divided by the total time to give the number of fluctuations per second. The results are shown in Table I.

Table I

MEASURING STATION

| River flow cfs | Fluctuations/second | | | | |
|---|---|---|---|---|---|
| | 1R | 4R | 5R | 1L | 4L |
| 266,000 | 1.4 | * | 1.5 | * | * |
| 313,000 | 0.7 | 0.8 | 0.9 | 1.0 | 0.7 |
| 346,000 | * | 1.3 | 1.0 | 1.0 | 0.6 |

*No record

Table I may be used with the charts of Figure 5 to determine for a given length of time approximately how many fluctuations of a given magnitude may be expected. For example, at Station 1R, river flow of 313,000 cfs for a period of 1 hour, from Table I, there would be 2,520 fluctuations during the hour. If the fluctuation in question was of a magnitude of 4 feet, then from Figure 5A, for 313,000 cfs, 11 percent, or approximately 270 fluctuations at 1R would be 4 feet in height.

## Measurement by Pile Hammer

The measurement of water surface fluctuation at Stations 1, 2, 3, and 4 by means of the staff painted on the pile hammer, was unsuccessful. Forces exerted by waves and water velocity moved the pile hammer to such an extent that the reading of the staff was practically impossible.

## Pressure Cell on Pile Hammer

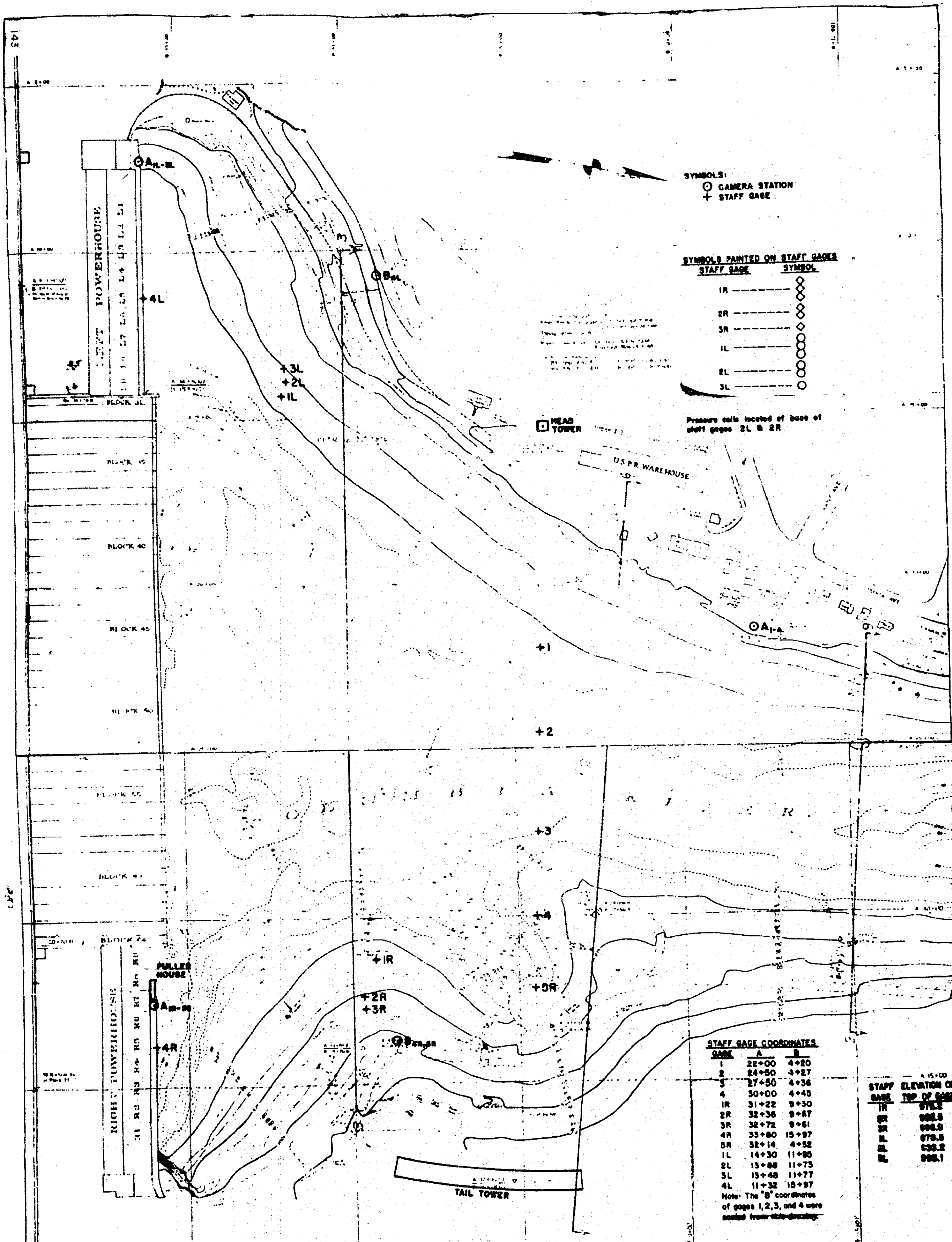
No conclusion resulted from the meager and inconsistent information obtained from the pressures registered by the cell mounted on the pile hammer and their relation to the height of the water surface fluctuations.

## Surface Velocity in Tail Bay--1:60 Model

Water surface velocities along the tail bay riverbanks in the 1:60 model were obtained for river flows representing 266,000, 500,000, and 750,000 cfs. These discharges were used for both the present and ultimate topography plans with the resulting velocities shown in Figures 9 and 10. The maximum prototype velocity in the tail bay indicated by these data was 7.7 feet per second at a discharge of 750,000 cfs. This velocity occurred for both topography plans on the riverbank immediately downstream of the left powerhouse and near Station B, 0+00 on both riverbanks for the present plan. With the flattened slopes in the ultimate topography plan, the increase in cross-sectional areas will result in a general reduction in the velocities throughout the tail bay.

## Movement of Riprap

Groups of rocks at various stations on both sides of the tailrace banks were located by survey and marked before high water of May 1949. Individual rocks of the groups varied in shape and weight and were chosen at random to represent a general gradation of riprap in the area (Figure 11, 12, 13, and 14). After the flood season, a re-survey noted the movement of the rocks that remained (Figure 15). Many of the rocks and some groups were not recovered because of readjustments of the riprap cover. Those rocks moved and recovered after the flood indicate the extent of readjustment.




**STAFF GAGE COORDINATES**

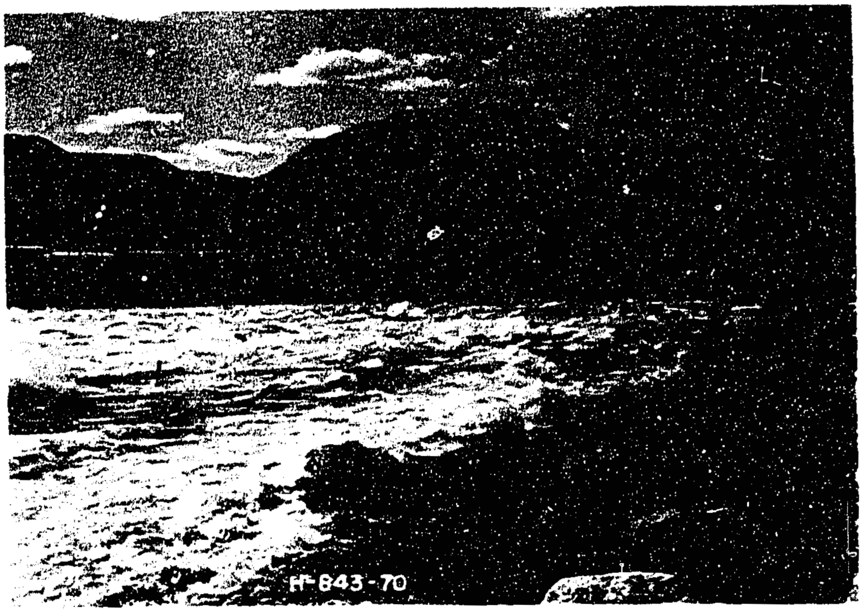
| GAGE | A | B |
|---|---|---|
| 1 | 22+00 | 4+20 |
| 2 | 24+50 | 4+27 |
| 3 | 27+50 | 4+36 |
| 4 | 30+00 | 4+45 |
| 1R | 31+22 | 9+30 |
| 2R | 32+36 | 9+67 |
| 3R | 32+72 | 9+61 |
| 4R | 33+80 | 15+97 |
| 5R | 32+14 | 4+52 |
| 1L | 14+30 | 11+85 |
| 2L | 13+88 | 11+73 |
| 3L | 13+48 | 11+77 |
| 4L | 11+32 | 15+97 |

Note: The "B" coordinates of gages 1, 2, 3, and 4 were ~~scaled from this drawing~~

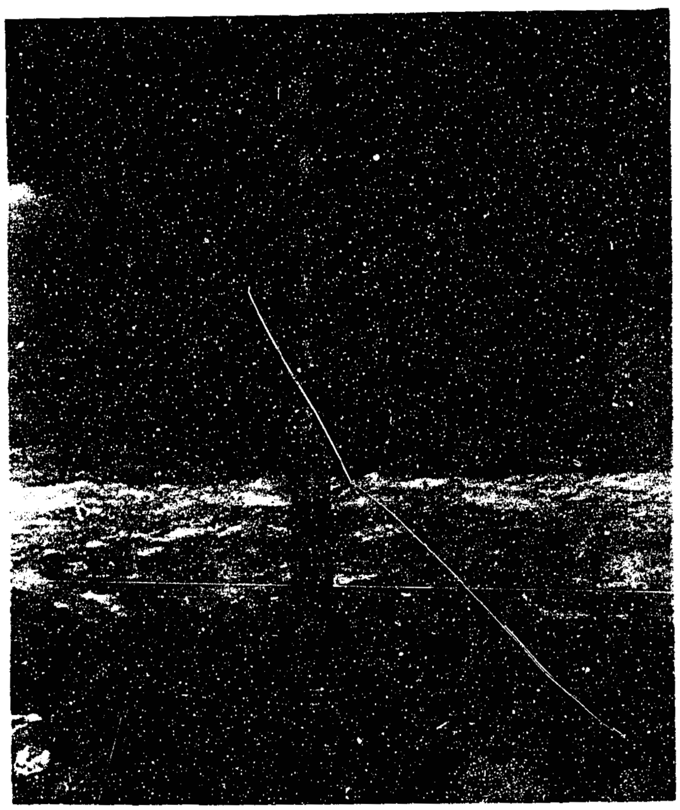
| STAFF GAGE | ELEVATION OF TOP OF GAGE |
|---|---|
| 1R | [illegible] |
| 2R | [illegible] |
| 3R | 986.9 |
| 1L | 979.5 |
| 2L | 930.2 |
| 3L | 986.1 |

COLUMBIA BASIN PROJECT
GRAND COULEE DAM
WAVE STUDIES - PRESENT TOPOGRAPHY
LOCATIONS OF STAFF GAGES & PHOTOGRAPHIC STATIONS
JULY 13, 1949

FIGURE I
REPORT HYD.336

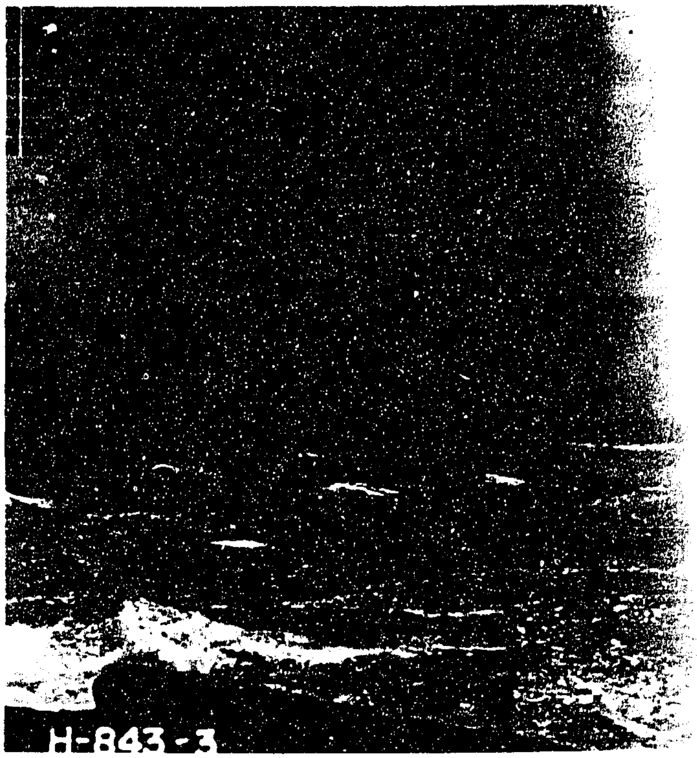



A. Staff gages 1R and 2R on right bank of Grand Coulee Dam tailbay - River Flow 313,000 cfs



B. Staff gage 1L on left bank of Grand Coulee Dam tailbay River Flow 215,000 cfs

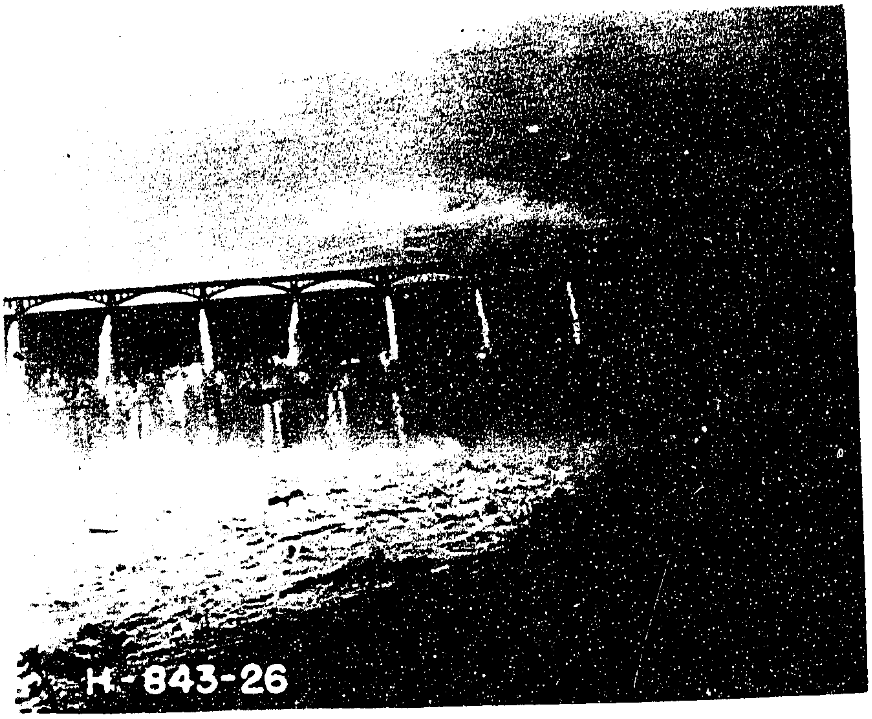
Wave Action at Staff Gages
Wave Studies - Grand Coulee Dam



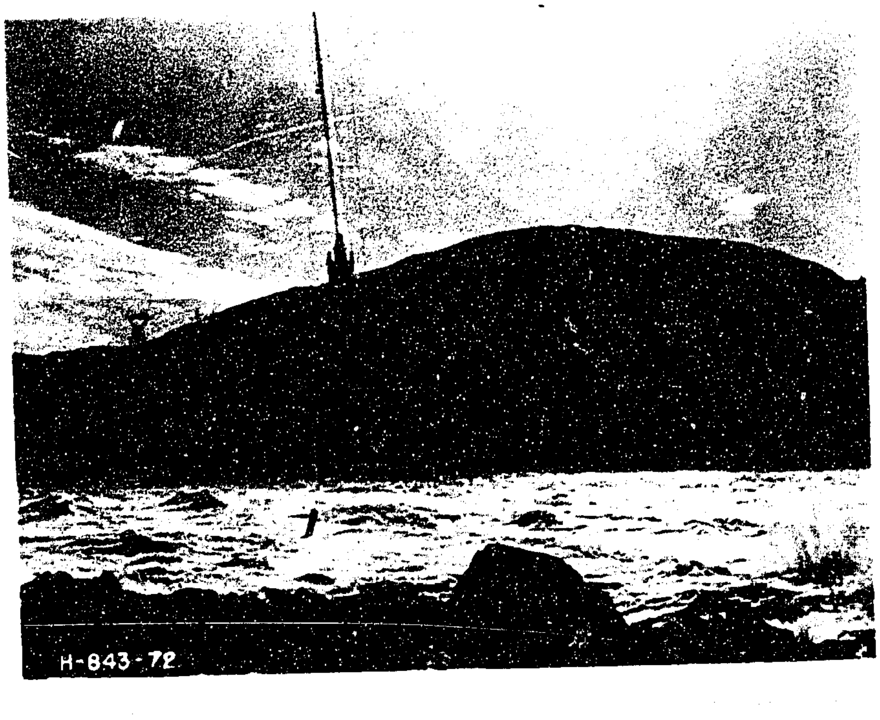

A. Right powerhouse staff gage 4R - River Flow 175,000 cfs

B. Staff gage on Number 1 access tower of the bucket caisson - River Flow 313,000 cfs

Wave Action at Right Powerhouse and Cassion Staff Gages
Wave Studies - Grand Coulee Dam

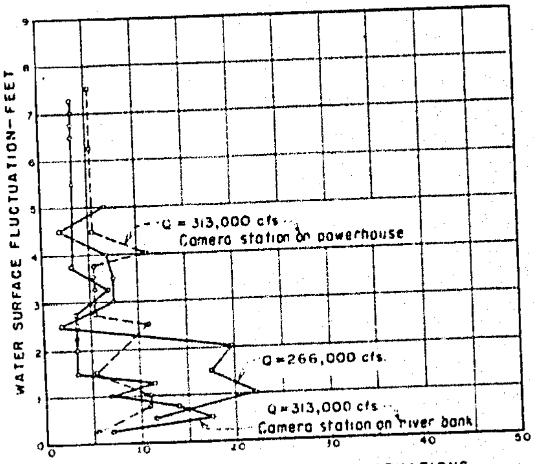



A. 10-ton pile driver hammer staff gage in operation
River Flow 313,000 cfs

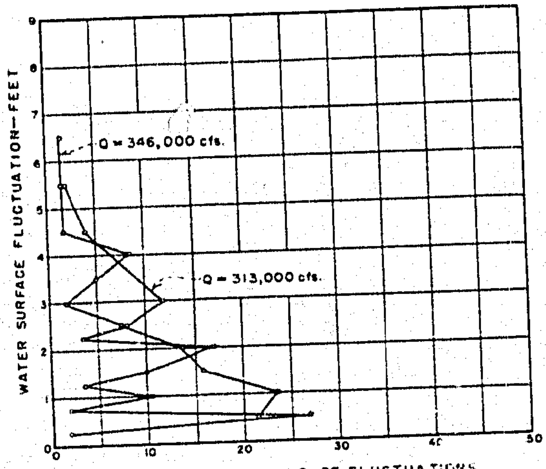



B. Movement of pile hammer by forces exerted by waves and water velocity - River Flow 346,000 cfs

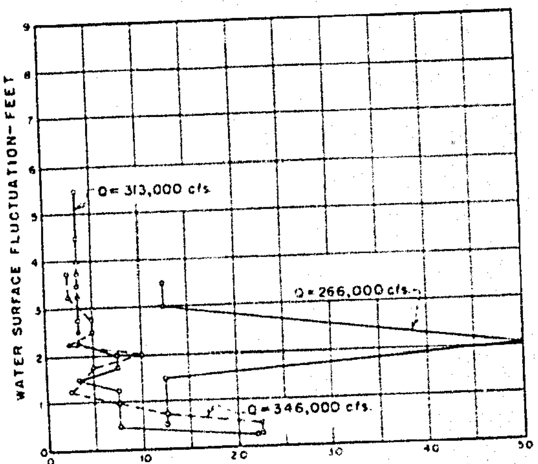
Wave Action in River at Pile Hammer Gage Stations
Wave Studies - Grand Coulee Dam



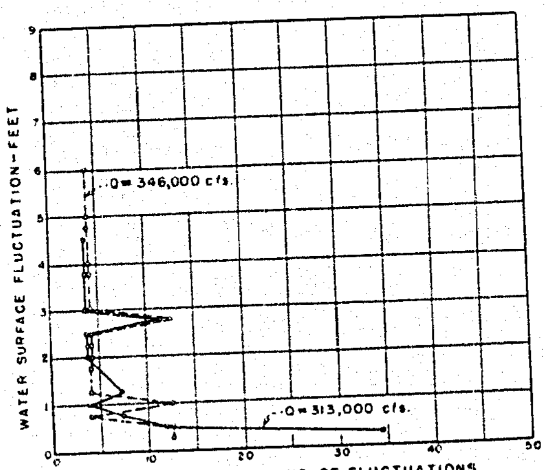

PERCENT OF TOTAL NO. OF FLUCTUATIONS
A. LOWEST STAFF GAGE RIGHT SIDE—1R



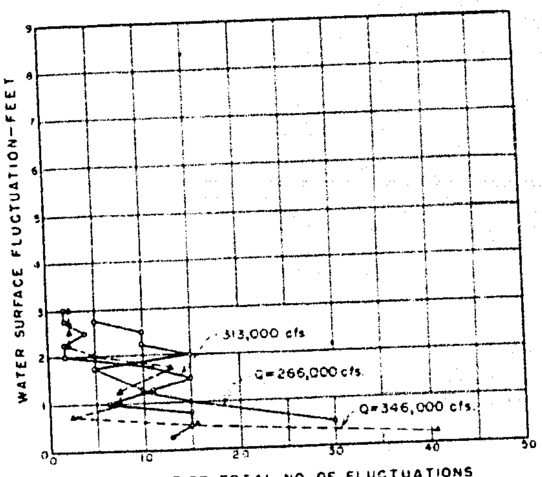

PERCENT OF TOTAL NO. OF FLUCTUATIONS
B. LOWEST STAFF GAGE LEFT SIDE—1L



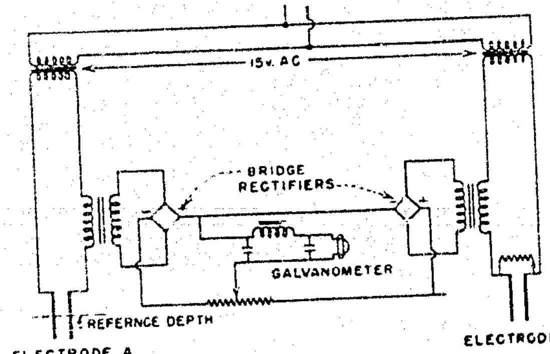

PERCENT OF TOTAL NO. OF FLUCTUATIONS
C. RIGHT POWERHOUSE 4R




PERCENT OF TOTAL NO. OF FLUCTUATIONS
D. LEFT POWERHOUSE 4L

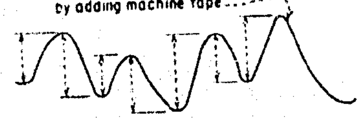



PERCENT OF TOTAL NO. OF FLUCTUATIONS
E. CAISSON ACCESS SHAFT 5R



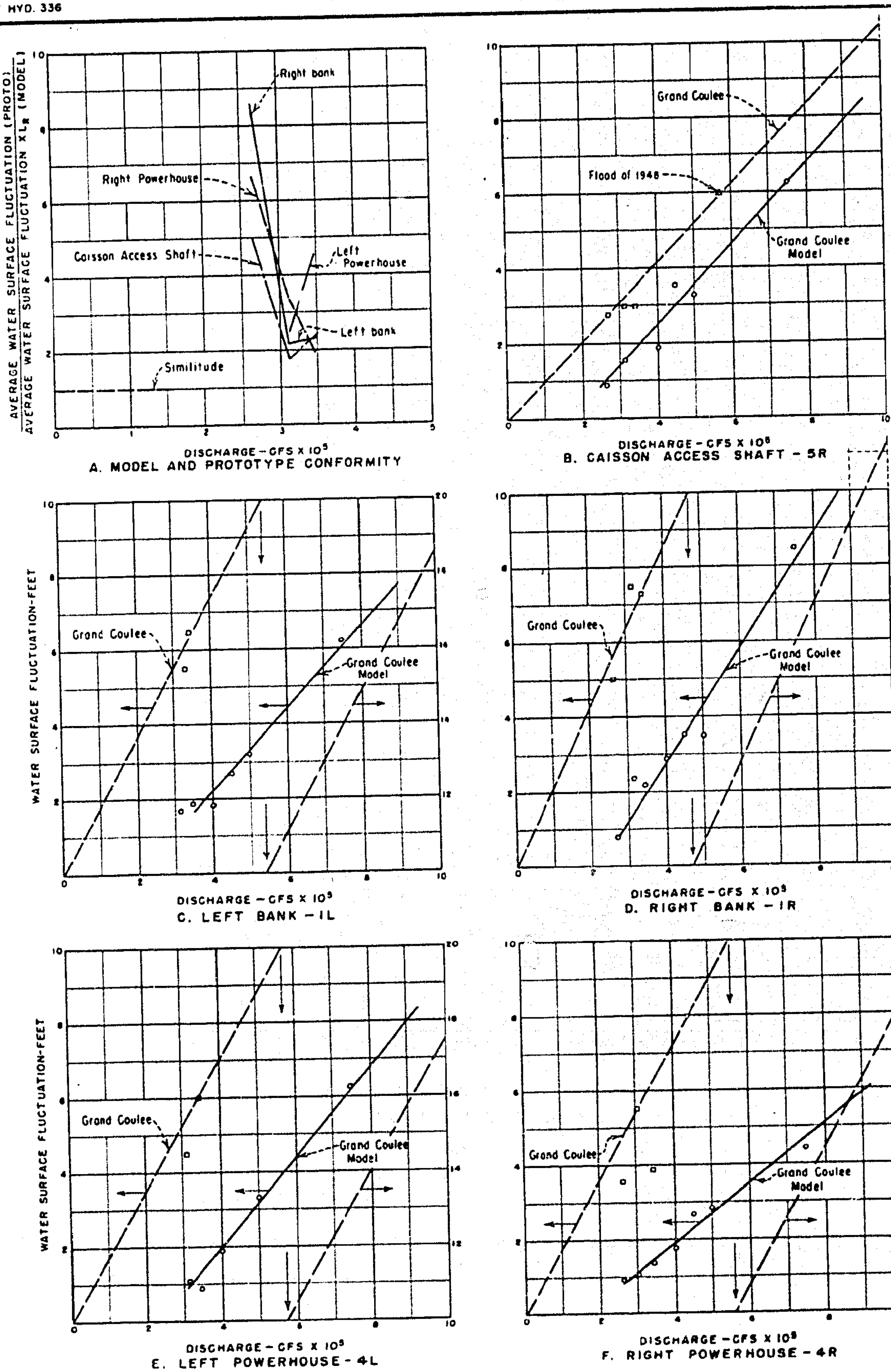

G. MODEL WAVE MEASURING CIRCUIT
(SCHEMATIC)

Type of surface fluctuation indicated by adding machine tape

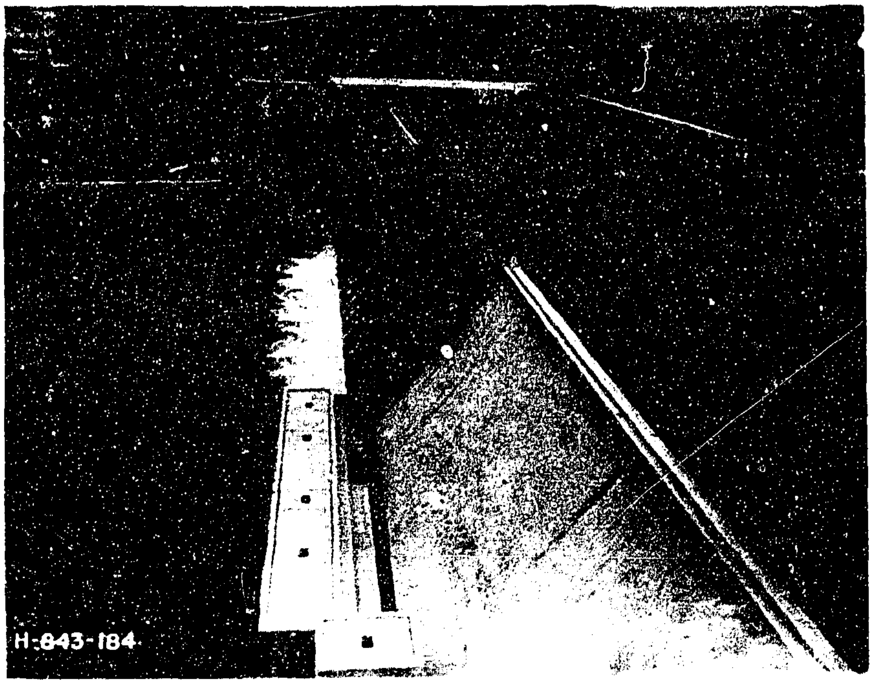


EACH DIMENSION REPRESENTS 1 FLUCTUATION
F. WATER SURFACE FLUCTUATION
(SCHEMATIC)

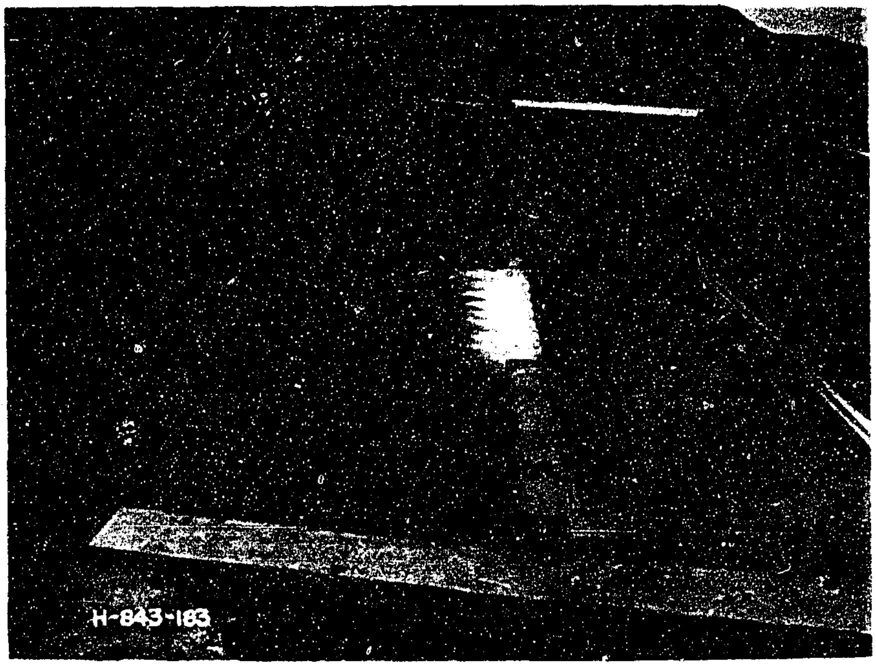
WATER SURFACE FLUCTUATION AT
MEASURING STATIONS
WAVE STUDIES—GRAND COULEE DAM




COMPARISON OF MODEL AND PROTOTYPE
WATER SURFACE FLUCTUATION
WAVE STUDIES - GRAND COULEE DAM

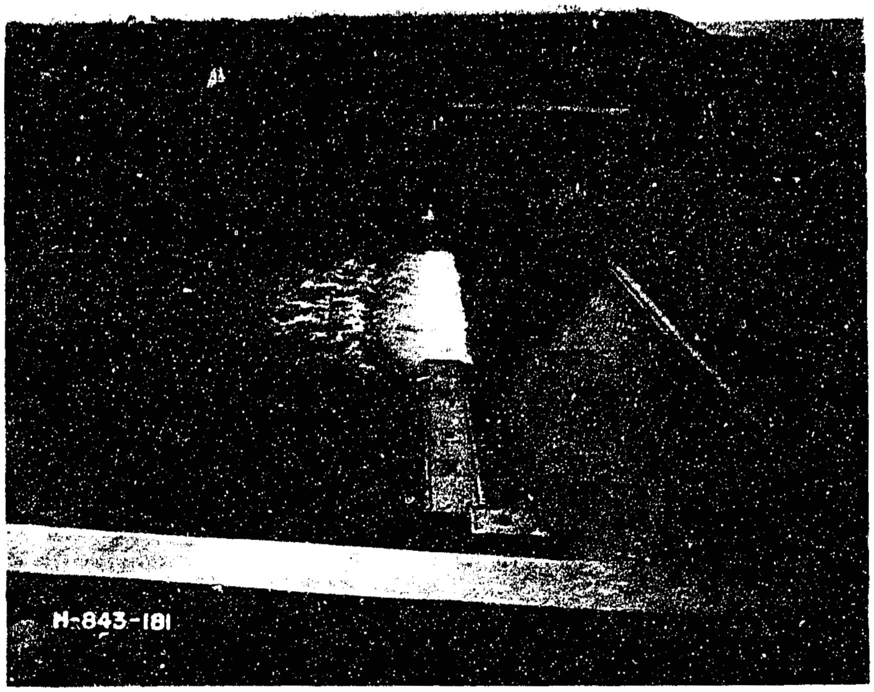



A. 1:60 Model of Grand Coulee Dam operating at a discharge representing 266,000 cfs

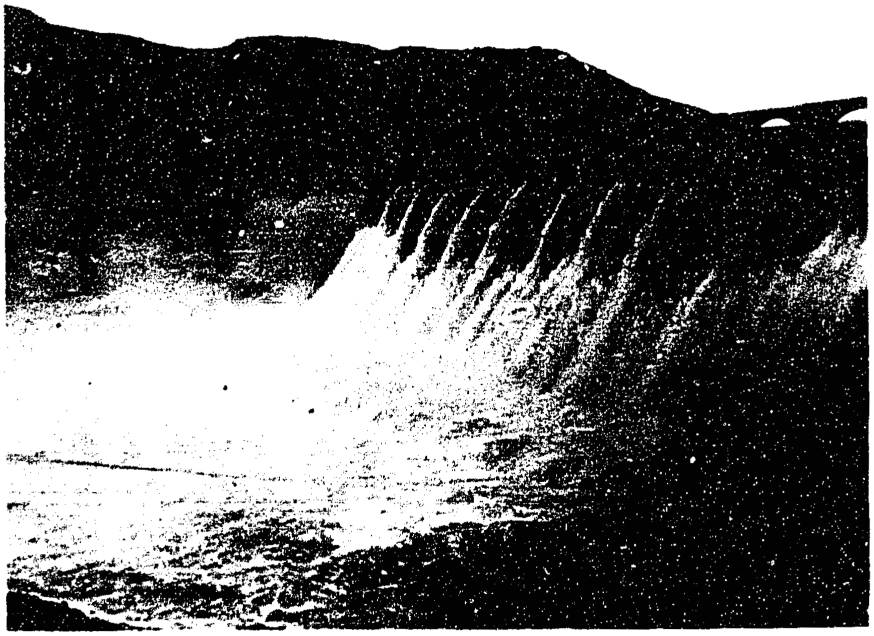



B. 1:60 Model of Grand Coulee Dam operating at a discharge representing 346,000 cfs

Model - Conditions for Discharges Representing 266,000 and 346,000 cfs
Wave Studies - Grand Coulee Dam

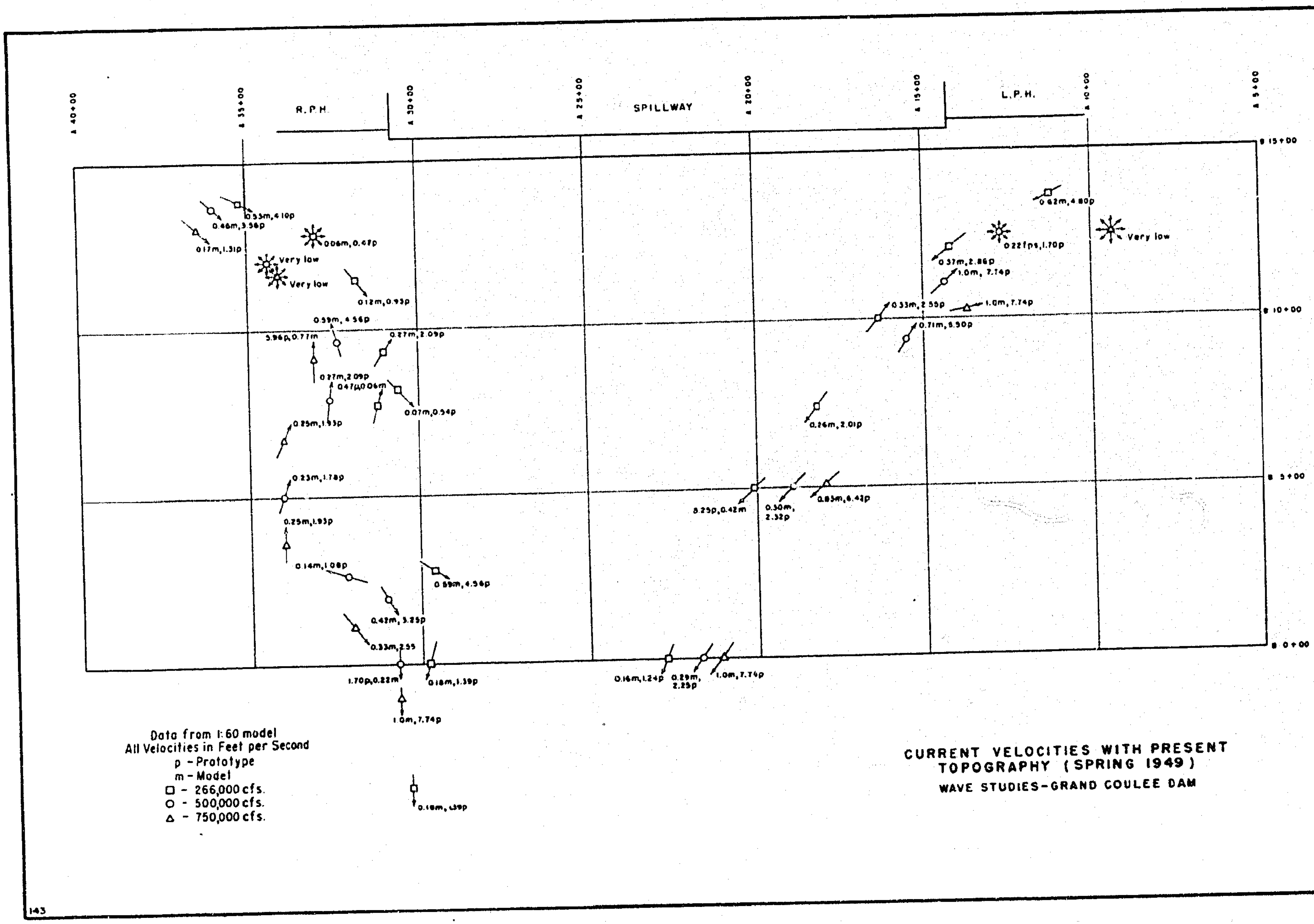



A. 1:60 Model of Grand Coulee Dam operating at a discharge representing 500,000 second feet



B. Grand Coulee Dam operating at a discharge of 570,000 second feet

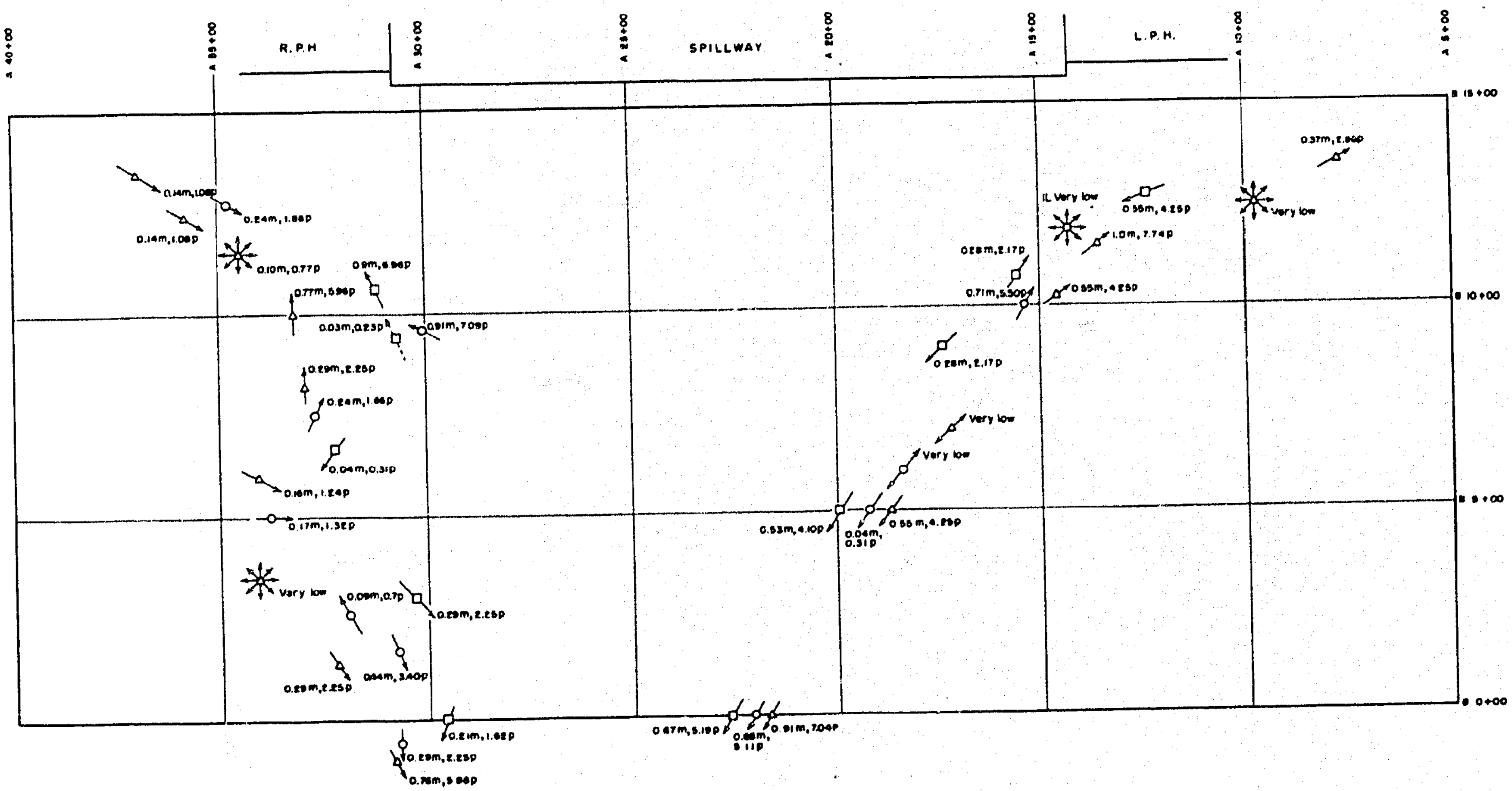
Flow Conditions for Model Operating at Flow Representing 500,000 cfs and for Prototype with 570,000 cfs
Wave Studies - Grand Coulee Dam




CURRENT VELOCITIES WITH PRESENT TOPOGRAPHY (SPRING 1949)
WAVE STUDIES-GRAND COULEE DAM

FIGURE 9
REPORT HYD. 336

FIGURE 10
REPORT HYD. 336




Data from 1:60 model
All Velocities in Feet per Second
p - Prototype
m - Model
□ - 266,000 cfs.
○ - 500,000 cfs.
△ - 750,000 cfs

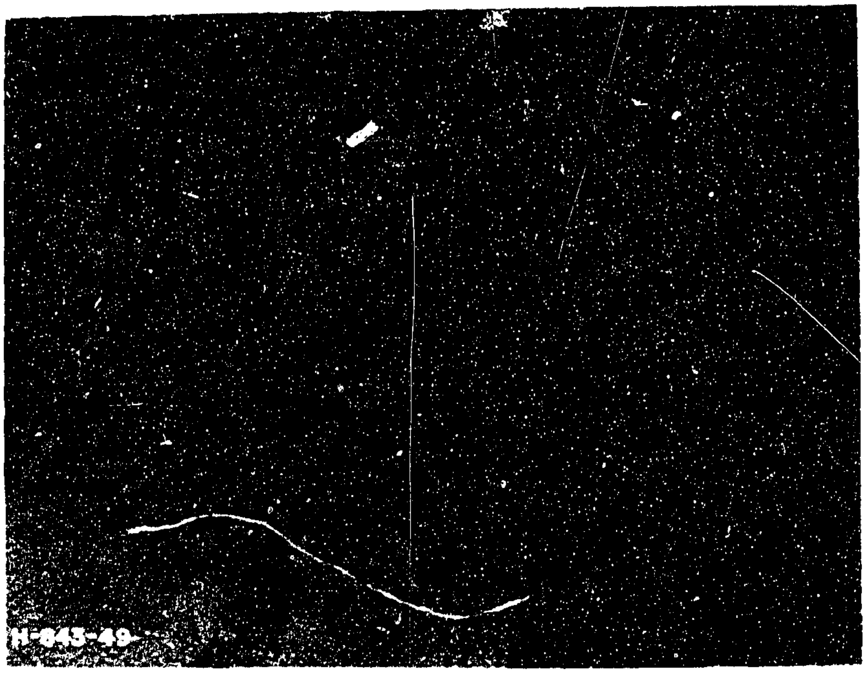
**CURRENT VELOCITIES WITH ULTIMATE TOPOGRAPHY**

**WAVE STUDIES - GRAND COULEE DAM**

A. Marked Riprap, group "A", Station A34+55.33, B12+59.05

B. Marked Riprap, group "C", Station A32+73.84, B11+06.63

Original Rock Positions - Marked Riprap Groups A and C on Right or East River Bank
Wave Studies - Grand Coulee Dam




A. Marked Riprap, group "A", Station A34+55.33, B12+59.05

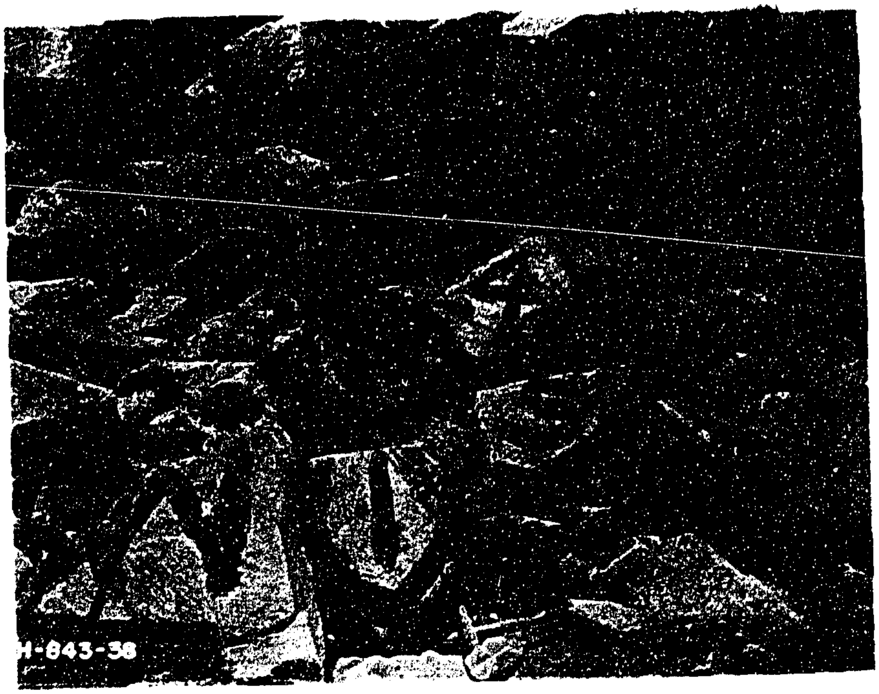
B. Marked Riprap, group "C", Station A32+73.84, B11+06.63

Original Rock Positions - Marked Riprap Groups A and C on Right or East River Bank
Wave Studies - Grand Coulee Dam

A. Marked Riprap group "D", Station A32+35.28, B9+96.73

B. Marked Riprap group "G", Station A33+81.42, B4+17.37

Original Rock Positions - Marked Riprap Groups D and G on Right or East River Bank
Wave Studies - Grand Coulee Dam

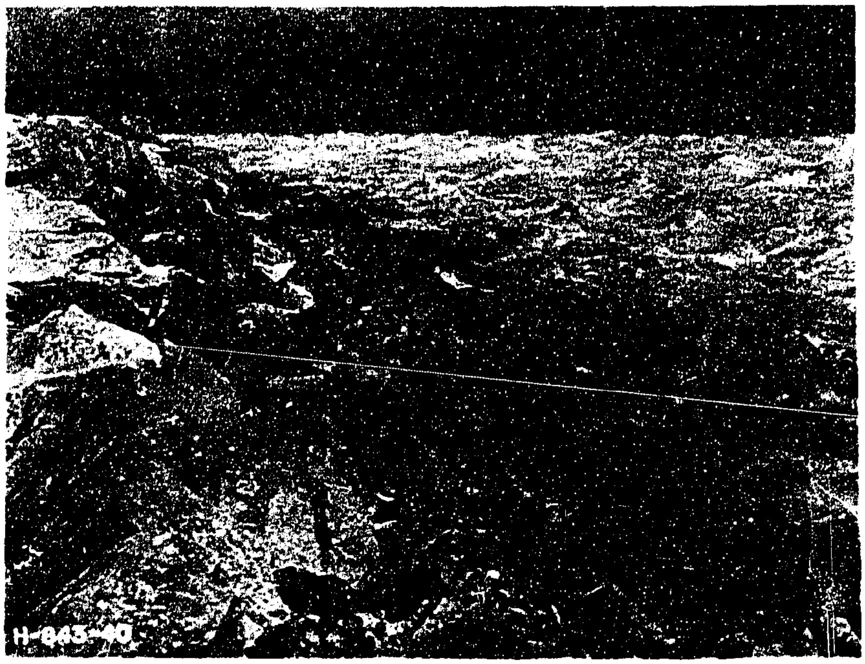



A. Marked Riprap, group "N", Station A12+79.8, B12+19.1


B. Marked Riprap, group "D", Station A14+34, B11+40

Original Rock Positions - Marked Riprap Groups N and D on Left or West River Bank
Wave Studies - Grand Coulee Dam

Figure 14
Report Hyd 336



A. Marked Riprap, group "D", Station A14+34, B11+40

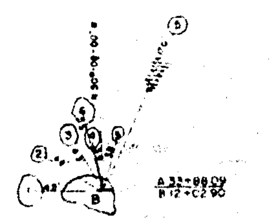
B. Marked Riprap group "Y", Station A15+06.4, B10+68.6

Original Rock Position - Marked Riprap Groups D and Y on Left or West River Bank
Wave Studies - Grand Coulee Dam

## MOVEMENT OF ROCKS IN RIVER STUDY EAST BANK

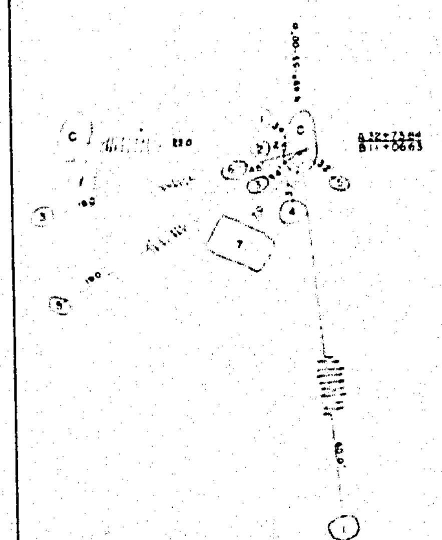
| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| A | 40'x15'x10' | 9713 | | LOST |
| 1 | 10'x05'x05' | 9698 | | LOST |
| 2 | 10'x10'x05' | 9702 | 9719 | ONLY ROCK RECOVERED |
| 3 | 08'x06'x04' | 9697 | | LOST |
| 4 | 08'x10'x05' | 9693 | | " |
| 5 | 06'x06'x02' | 9699 | | " |

| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| B | 28'x17'x12' | 9714 | | |
| 1 | 15'x25'x14' | 9706 | | |
| 2 | 09'x09'x07' | 9694 | | |
| 3 | 18'x08'x05' | 9697 | | |
| 4 | 13'x09'x05' | 9699 | | |
| 5 | 11'x10'x06' | 9702 | 9724 | ONLY ROCK RECOVERED |
| 6 | 22'x12'x06' | 9700 | | |



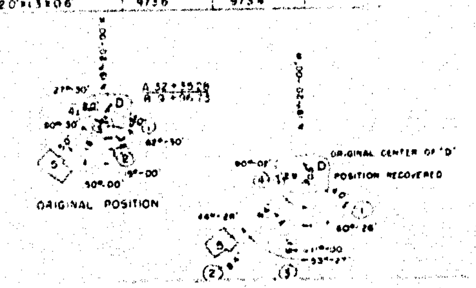
## MOVEMENT OF ROCKS IN RIVER STUDY EAST BANK

| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| C | 40'x20'x20' | 9715 | 9683 | |
| 1 | 15'x12'x07' | 9705 | 9742 | |
| 2 | 16'x15'x06' | 9698 | | LOST |
| 3 | 17'x12'x10' | 9702 | 9679 | |
| 4 | 18'x13'x12' | 9706 | | LOST |
| 5 | 24'x12'x11' | 9710 | 9688 | |
| 6 | 19'x11'x13' | 9706 | | LOST |
| 7 | 39'x26'x-' | 9694 | 9695 | NO MOVEMENT |

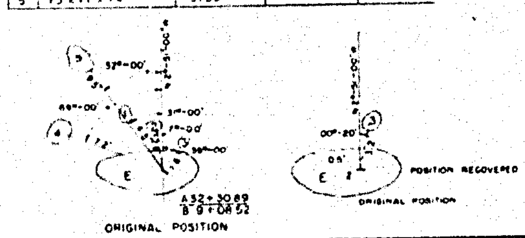


## MOVEMENT OF ROCKS IN RIVER STUDY EAST BANK

| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| D | 20'x18'x27' | 9748 | 9749 | |
| 1 | 20'x20'x18' | 9750 | 9750 | |
| 2 | 16'x21'x08' | 9751 | 9734 | |
| 3 | 10'x19'x05' | 9740 | 9743 | |
| 4 | 24'x16'x09' | 9732 | 9732 | |
| 5 | 20'x13'x06' | 9736 | 9734 | |

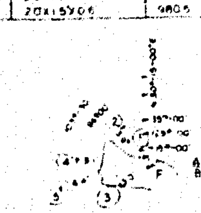



| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| E | 65'x35'x20' | 9766 | 9767 | |
| 1 | 10'x10'x03' | 9745 | | LOST |
| 2 | 10'x09'x05' | 9750 | | LOST |
| 3 | 13'x12'x11' | 9756 | 9751 | |
| 4 | 25'x16'x11' | 9743 | | LOST |
| 5 | 15'x11'x14' | 9739 | | LOST |

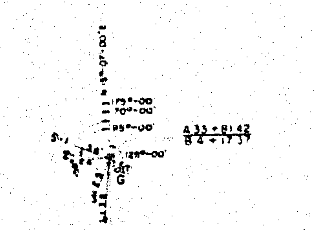



## MOVEMENT OF ROCKS IN RIVER STUDY EAST-BANK

| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| F | 54'x38'x24' | 9858 | NO CHANGE | IN LOC OR EL |
| 1 | 24'x22'x10' | 9852 | " | " |
| 2 | 16'x14'x07' | 9826 | " | " |
| 3 | 27'x17'x11' | 9865 | " | " |
| 4 | 26'x13'x09' | 9815 | " | " |
| 5 | 20'x15'x06' | 9805 | " | " |

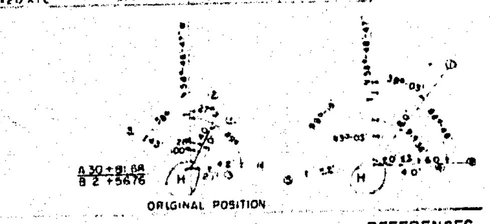


| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| G | 21'x12'x15' | 9761 | NO ROCKS RECOVERED | |
| 1 | 14'x09'x06' | 9755 | | |
| 2 | 15'x18'x16' | 9746 | | |
| 3 | 12'x06'x05' | 9745 | | |
| 4 | 13'x08'x07' | 9740 | | |
| 5 | 23'x17'x09' | 9756 | | |



## MOVEMENT OF ROCKS IN RIVER STUDY EAST BANK

| NO | SIZE | ORIG EL | RECOV EL | REMARKS |
|---|---|---|---|---|
| H | 33'x27'x15' | 9753 | 9752 | |
| 1 | 14'x09'x06' | 9742 | 9740 | |
| 2 | 10'x08'x07' | 9743 | 9753 | |
| 3 | 16'x10'x05' | 9745 | 9742 | |
| 4 | 13'x10'x11' | 9747 | 9746 | |
| 5 | 27'x20'x10' | 9747 | 9742 | |




### UPPER STAFF GAUGE

Original location A 32+72.13 B 9+61.35 elev 996.86 (top of gauge)
Present location – no change

### MIDDLE STAFF GAUGE

Original location A 32+36.49 B 9+67.31 elev 986.48 (top of gauge)
Present location – no change

### LOWER STAFF GAUGE

Original location A 31+21.55 B 9+29.74 elev 975.23 (top of gauge)
Present location A 31+21.84 B 9+27.09 elev 960.0 (ground elev.)
Note This gauge was washed out by high water and the present location is of the footing block only

### REFERENCES

May 15, 1949 (original survey) BR 184
June 21, 1949 (re-survey) BR 184

### NOTE

Individual pieces of riprap were located and marked before high water of 1949. After the river receded, a re-survey of the marked riprap was made and movement noted.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT – WASHINGTON
GRAND COULEE DAM
RIVER STUDY – EAST RIVERBANK
MOVEMENT OF RIPRAP
HIGH WATER – 1949

DRAWN G.E.M. SUBMITTED
TRACED M.G.H. RECOMMENDED
CHECKED R.N.M. APPROVED

COULEE DAM, WASH 12-22-49 222-P-10731

## MOVEMENT OF ROCKS IN RIVER STUDY WEST BANK

### GROUP "C"

| NO | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 13'x07'x05' | 9+24.4 | 13+95.3 | 9683 | | | | NOT FOUND | |
| 2 | 14'x09'x08' | 9+25.9 | 14+02.3 | 9682 | 9+26.8 | 14+02.5 | 9675 | S79°47'W+0.9' | -0.7' |
| 3 | 11'x13'x04' | 9+24.1 | 14+01.7 | 9681 | 9+25.6 | 14+03.6 | 9679 | S38°44'E+2.5' | -0.3 |
| 4 | 15'x08'x08' | 9+23.9 | 14+02.7 | 9696 | 9+24.2 | 14+02.9 | 9691 | S59°02'W+0.3' | -0.5' |
| 5 | 13'x15'x09' | 9+20.9 | 14+01.9 | 9700 | 9+21.2 | 14+01.2 | 9689 | S10°59'W+1.4' | -1.1' |
| 6 | 19'x28'x06' | 9+21.3 | 13+98.4 | 9700 | 9+21.6 | 13+99.9 | 9698 | S17°57'E+1.6' | -0.2' |
| 7 | 26'x18'x08' | 9+23.7 | 14+04.9 | 9682 | 9+25.9 | 14+05.2 | 9678 | S29°03'W+0.3' | -0.4 |

### GROUP "A"

| NO | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| A | 55'x12'x05' | 11+35.9 | 12+98.6 | 9738 | 11+3[illegible] | 12+98.5 | 9738 | N17°16'W+0.3 | 0.0' |
| 1 | 18'x11'x19' | 11+38.9 | 12+96.8 | 9707 | 11+34.2 | 12+97.4 | 9709 | S30°58'E+0.7' | +0.2' |
| 2 | 12'x21'x06' | 11+41.7 | 13+02.0 | 9699 | 11+38.1 | 12+99.3 | 9703 | N48°09'W+4.9' | +0.4' |
| 3 | 22'x18'x10' | 11+35.0 | 13+06.8 | 9697 | 11+28.0 | 13+05.9 | 9703 | N42°03'W+7.1' | +0.6' |
| 4 | 14'x12'x05' | 11+39.3 | 13+00.2 | 9706 | 11+36.7 | 12+98.0 | 9697 | S49°36'W+3.4 | -0.9' |
| 5 | 15'x08'x06' | 11+40.1 | 13+00.6 | 9704 | 11+32.0 | 13+04.4 | 9690 | S64°14'W+9.0 | -1.4 |

## MOVEMENT OF ROCKS IN RIVER STUDY WEST BANK

### GROUP "N"

| NO | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| N | 25'x16'x17' | 12+79.8 | 12+19.1 | 9822 | 12+79.3 | 12+18.8 | 9821 | N59°49'W+0.6 | -0.1' |
| 1 | 15'x16'x16' | 12+82.3 | 12+18.6 | 9819 | 12+81.4 | 12+18.2 | 9818 | N64°28'W+1.0' | -0.1' |
| 2 | 18'x16'x14' | 12+78.6 | 12+17.4 | 9828 | 12+78.6 | 12+17.4 | 9828 | NO CHANGE | 0.0' |
| 3 | 14'x12'x06' | 12+80.3 | 12+15.2 | 9854 | 12+80.4 | 12+15.2 | 9854 | NO CHANGE | 0.0 |
| 4 | 16'x21'x15' | 12+84.6 | 12+13.8 | 9841 | 12+86.5 | 12+18.4 | 9824 | S22°04'W+5.0' | -1.7 |
| 5 | 18'x17'x05' | 12+85.1 | 12+15.1 | 9821 | 12+84.5 | 12+17.0 | 9819 | S17°16'W+2.0' | -0.2 |
| 6 | 16'x19'x09' | 12+85.6 | 12+16.0 | 9816 | 12+84.5 | 12+16.5 | 9815 | S24°27'W+2.8' | -0.1 |
| 7 | 11'x14'x04' | 12+87.9 | 12+11.9 | 9827 | 12+89.0 | 12+13.6 | 9814 | S31°55'E+2.0' | -1.3' |
| 8 | 17'x13'x03' | 12+89.1 | 12+11.0 | 9828 | MISSING | | | | |
| 9 | 24'x34'x20' | 12+83.7 | 12+12.6 | 9853 | 12+84.6 | 12+15.5 | 9844 | S26°34'E+3.2' | -0.9' |

### UPPER STAFF GAUGE

Original location A 13+48.4 B 11+77.4 El 998.1 (top of gauge)
Present location – no change

### MIDDLE STAFF GAUGE

Original location A 13+88.1 B 11+72.8 El 988.2 (top of gauge)
Present location – no change

### LOWER STAFF GAUGE

Original location A 14+30.1 B 11+84.6 El 978.5 (top of gauge)
Present location – no change

## MOVEMENT OF ROCKS IN RIVER STUDY WEST BANK

### GROUP "D"

| NO | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 35'x25'x36' | 13+76.2 | 11+65.2 | 9715 | 13+79.2 | 11+99.0 | 9708 | S5°07'E+34.0' | -0.7' |
| 2 | 03'x08'x11' | 14+06.4 | 11+71.3 | 9697 | | | | LOST | |
| 3 | 09'x11'x18' | 14+17.8 | 11+59.3 | 9714 | | | | LOST | |
| 4 | 34'x32'x16' | 14+25.2 | 11+53.0 | 9762 | | | | LOST | |
| 5 | 21'x18'x19' | 14+29.9 | 11+48.7 | 9793 | 14+35.4 | 11+58.2 | 9715 | S20°13'E+10.1' | -7.8' |
| 6 | 17'x15'x24' | 14+26.1 | 11+40.6 | 9855 | 14+55.0 | 11+23.1 | 9685 | N58°46'E+33.8' | -15.0' |
| 7 | 16'x16'x13' | 14+34.3 | 11+37.0 | 9835 | | | | LOST | |
| 8 | 13'x16'x14' | 14+33.2 | 11+35.1 | 9831 | | | | LOST | |
| 9 | 36'x35'x23' | 14+52.8 | 11+52.1 | 9828 | | | | LOST | |
| 10 | 19'x16'x12' | 14+68.1 | 11+15.3 | 9762 | | | | LOST | |
| 11 | 20'x19'x30' | 14+71.5 | 11+14.9 | 9759 | 14+81.0 | 11+51.2 | 9633 | S14°39'E+37.5' | -12.6' |
| 12 | 24'x26'x11' | 14+70.1 | 11+12.1 | 9767 | 14+86.6 | 11+38.6 | 9623 | S31°51'E+31.2' | -14.4' |
| 13 | 37'x20'x13' | 14+64.6 | 11+08.3 | 9823 | 14+67.9 | 11+68.2 | 9603 | S34°07'E+60.0' | -22.0' |
| 14 | 46'x35'x40' | 14+48.2 | 11+12.3 | 965.3 | | | | LOST | |

## MOVEMENT OF ROCKS IN RIVER STUDY WEST BANK

### GROUP "Y"

| NO | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| Y | 60'x38'x41' | 15+12.3 | 10+35.6 | 9874 | 15+27.4 | 10+38.0 | 9788 | S80°56'E+15.3' | -8.6 |
| 1 | 11'x05'x05' | 15+07.6 | 10+66.8 | 9830 | | | | LOST | |
| 2 | 08'x15'x04' | 15+07.7 | 10+66.0 | 9830 | | | | LOST | |
| 3 | 09'x12'x08' | 15+04.3 | 10+67.6 | 9829 | | | | LOST | |
| 4 | 08'x07'x06' | 15+05.2 | 10+66.8 | 9825 | | | | LOST | |
| 5 | 37'x29'x15' | 15+07.0 | 10+63.2 | 9832 | | | | LOST | |
| 6 | 07'x12'x04' | 15+06.4 | 10+64.7 | 9829 | | | | LOST | |
| 7 | 12'x17'x05' | 15+09.0 | 10+61.0 | 9827 | | | | LOST | |
| 8 | 44'x20'x10' | 15+07.5 | 10+60.6 | 9839 | | | | LOST | |
| 9 | 36'x25'x19' | 15+09.0 | 10+61.7 | 9853 | | | | LOST | |
| Y' | 33'x39'x12' | 15+06.4 | 10+68.6 | 9831 | | | | LOST | |

### GROUP "S"

| NO | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| S | 13'x14'x04' | 15+45.7 | 10+14.9 | 9835 | | | | ROCKS COVERING ORIGINAL ROCKS | |
| 1 | 07'x10'x04' | 15+45.4 | 10+15.8 | 982[illegible] | | | | | |
| 2 | 08'x14'x04' | 15+42.6 | 10+13.0 | 9822 | | | | | |
| 3 | 12'x16'x08' | [illegible] | 10+10.7 | 9873 | | | | | |
| 4 | 08'x09'x05' | 15+44.3 | 10+12.2 | 9849 | | | | | |
| 5 | 13'x22'x09' | [illegible] | 10+0[illegible] | 982[illegible] | | | | | |

## MOVEMENT OF ROCKS IN RIVER STUDY WEST BANK

### GROUP "G"

| NO. | SIZE | ORIGINAL LOCATION A | ORIGINAL LOCATION B | ORIGINAL LOCATION EL | RE-SURVEY LOCATION A | RE-SURVEY LOCATION B | RE-SURVEY LOCATION EL | CHANGE IN POSITION | CHANGE IN ELEV |
|---|---|---|---|---|---|---|---|---|---|
| Z | 35'x60'x32' | 23+73.8 | -(6+90.0) | 9777 | 23+73.9 | -(6+90.0) | 9776 | NO MOVEMENT | |
| 1 | 29'x17'x08' | 23+70.6 | -(6+95.7) | 9771 | 23+71.9 | -(6+96.3) | 9763 | N66°42'E+1.4' | -0.8' |
| 2 | 15'x22'x26' | 23+76.1 | -(6+95.9) | 9747 | 23+77.0 | -(6+96.2) | 9733 | N73°56'E+0.9' | -1.4' |
| 3 | 26'x12'x26' | 23+70.0 | -(6+99.4) | 9799 | 23+70.7 | -(7+00.0) | 9792 | N51°27'E+0.9' | -0.7' |
| 4 | 25'x27'x13' | 23+65.8 | -(6+95.7) | 9817 | 23+66.9 | -(6+96.3) | 9809 | N60°49'E+1.3' | -0.8' |

### NOTE

Individual pieces of riprap were located and marked before high water of 1949. After the river receded, a re-survey of the marked riprap was made and movement noted, which is shown in the tabulation.

### REFERENCES

May 15, 1949 (original survey – Book BR 188)
June 21, 1949 (re-survey " " )

UNITED STATES
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COLUMBIA BASIN PROJECT – WASHINGTON
GRAND COULEE DAM
RIVER STUDY – WEST RIVERBANK
MOVEMENT OF RIPRAP
HIGH WATER – 1949

DRAWN G.E.M. SUBMITTED
TRACED M.G.H. RECOMMENDED
CHECKED R.N.M. APPROVED

COULEE DAM, WASH 2-27-49 222-P-10732